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SMAP SCIENCE RECOVERY EFFORTS*

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The Soil Moisture Active Passive (SMAP) spacecraft launched in January 2015, with a mission to produce global soil moisture maps every 1.5 days using a combination of active (radar) and passive (radiometer) L-band measurements. In July 2015, after 2.5 months in operation, the radar failed and was not able to transmit. While the radiometer was still producing excellent science measurements, the need to recover key active-passive soil moisture requirements was paramount. To that end, the science team found that the European Space Agency (ESA) had recently launched a C-band SAR spacecraft called Sentinel-1A (launched April 2014) in a similar orbit, which was seen as a potential replacement to the "active" part of the SMAP measurements. An analysis was performed to see what the resulting spatial and temporal coverage could be. The promising results of that coupled with the ramp up in global coverage from Sentinel-1A and 1B (launched April 2016) allowed SMAP to create a new joint science data product that strives to meet the original mission objectives. The joint product is now part of the routine release of SMAP data to the science community as of June 2018.

INTRODUCTION

SMAP is an orbiting observatory that measures the amount of water in the top 5 cm of soil everywhere on Earth. It also determines the freeze/thaw state of that top layer of soil. The observatory is in a sun-synchronous 8-day repeat orbit with 117 orbits per repeat cycle, and a 6 pm ascending node. This orbit when combined with an effective instrument swath width of 1000 km, gives a global coverage every 1.5 days. This effective swath is enabled by the use of a 6-m diameter reflecting mesh antenna, spinning at 14.6 revolutions per minute (rpm), to distribute the 30 km instrument footprint in a circular fashion which combines with the orbital motion for complete coverage (see Figure 1 for graphic representation).

After launch on January 31, 2015, the In-Orbit Commissioning (IOC) Phase commenced where the spacecraft reached the intended orbit, the antenna was spun up, and the instruments were turned on, calibrated, and the first data was collected. Two and a half months into the 36-month science phase, on July 7, 2015, the high-power amplifier for the radar instrument stopped drawing current and was never recovered, thus meaning the 'active' portion of the mission was lost. A Phase E reconfiguration review was completed in March 2016 and the project received

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approval by NASA Science Mission Directorate (SMD) to proceed as a radiometer-only mission. Earlier in the fall of 2015, the possibility was first raised to see about using data from the recently launched Sentinel-1B spacecraft to partially replace the data no longer generated from the radar.[1, 2, 3]

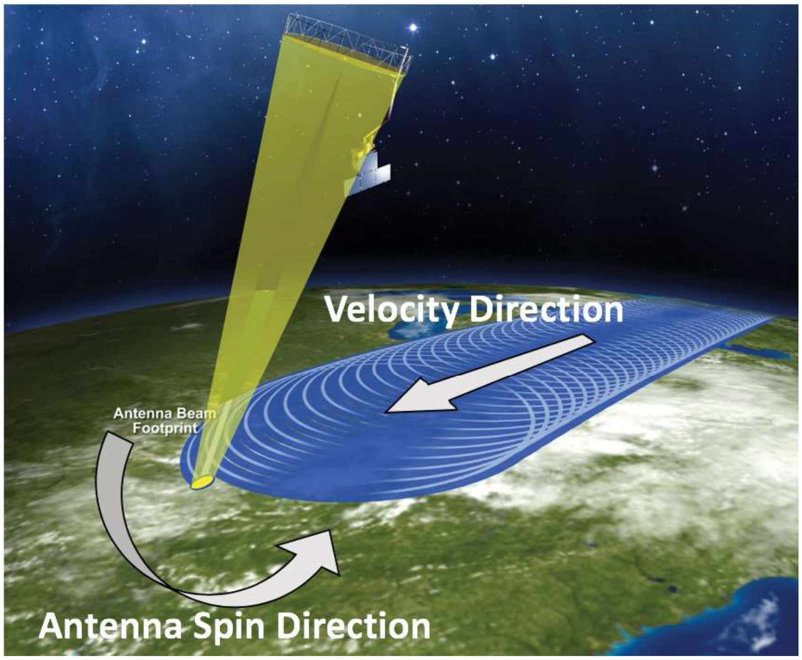

Figure 1 SMAP Data Gathering Concept.

The Sentinel-1A and 1B satellites are part of the Copernicus Programme conducted by ESA. They are in a sun-synchronous 12-day repeat orbit with 175 orbits per repeat cycle, and a 6 pm ascending node. Sentinel-1A was launched on April 3, 2014, and Sentinel-1B was launched on April 25, 2016. While there are many modes for the Sentinel-1 radar, for SMAP science recovery purposes the data from the dual-polarization interferometric wide-swath mode (IW mode, VV-VH) is the only one taken into consideration for being combined with radiometer data, with a swath width of ~250 km. This is because the co-pol (VV) and cross-pol (VH) observations are required for the SMAP active-passive algorithm. Fundamentally, 1A and 1B are separated by 180 degrees true anomaly, which leads to a repeat geometry revisit time of 6 days.[4]

COVERAGE STUDY

Given this multi-spacecraft arrangement, the amount of coverage that could be expected needed to be determined. To start, the SMAP 8-day repeat and the Sentinel-1 12-day repeat means there is a "common" repeat cycle of 24 days (consisting of 3 SMAP cycles and 2 Sentinel-1 cycles). For analysis purposes, the land area considered was the contiguous portion of the United States, where recovering high resolution soil moisture estimates was deemed a high priority. The main purpose of this study was to understand the rate of cumulative coverage as a function of time difference between a SMAP observation and a Sentinel-1 observation. This is because the longer the time difference between the observations, the less likely they are to be measuring the same soil moisture phenomena. The direction from the science team was that a time difference on the order of one day was likely acceptable.

Orbital/Radar Properties

The SMAP effective swath is 1000 km, centered on nadir. The Sentinel-1 dual-pol IW mode swath is a right-looking swath with near and far incidence angles of ~31 to 46 degrees, respectively. Figure 2 shows cartoon images comparing what this looks like. In this figure, the direction of travel is into the page, and the line normal to the earth surface represents nadir.

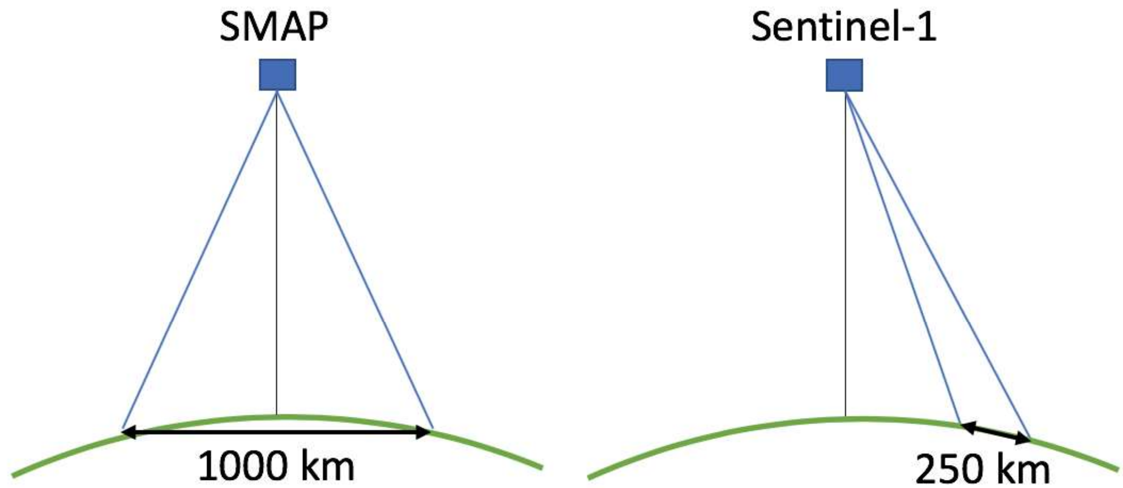

Figure 2 SMAP and Sentinel-1 Instrument Swaths Illustration (velocity direction into page, not to scale).

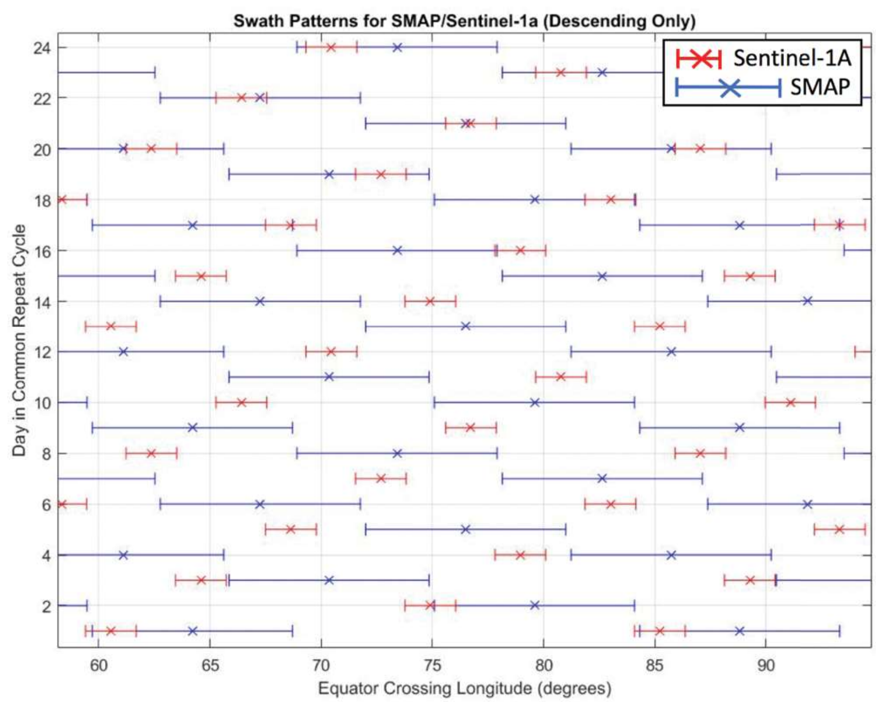

Figure 3 Sample SMAP/Sentinel-1 Swath Overlap.

To get a qualitative idea of how the coverage is distributed, it is possible and useful to combine the information of the orbit and the radar swaths to plot the equator crossings over time. Figure 3 shows the SMAP and Sentinel-1A descending equator crossing longitudes for a range of longitudes the width of consecutive SMAP descending equator crossings, versus the day in the common repeat cycle. It also shows the swath widths of each around each equator crossing. Immediately apparent is that the SMAP swath is so large that, if a Sentinel-1 swath isn't covered by it during the same day, it is definitely covered by it on an adjacent day. That combined with the relative difference in swath width means that the rate of coverage within one day of a SMAP observation will be somewhat lower than the SMAP-only rate of coverage. Note that while this figure shows a longitude region outside North America, the pattern shown in the longitude range continues around the equator.

Using a fine grid of points over the target area, and the orbit and radar swath assumptions listed above, we can calculate the minimum time difference over time of each point in the target area between a SMAP descending observation and the nearest observation within about a day by Sentinel-1 (A or B, ascending or descending). Figure 4 shows that there are three bins of time difference; within approximately one orbit period (~98 minutes), within ~12 hours, or within ~24 hours. The width of these time difference bins is about +/- one orbit period.

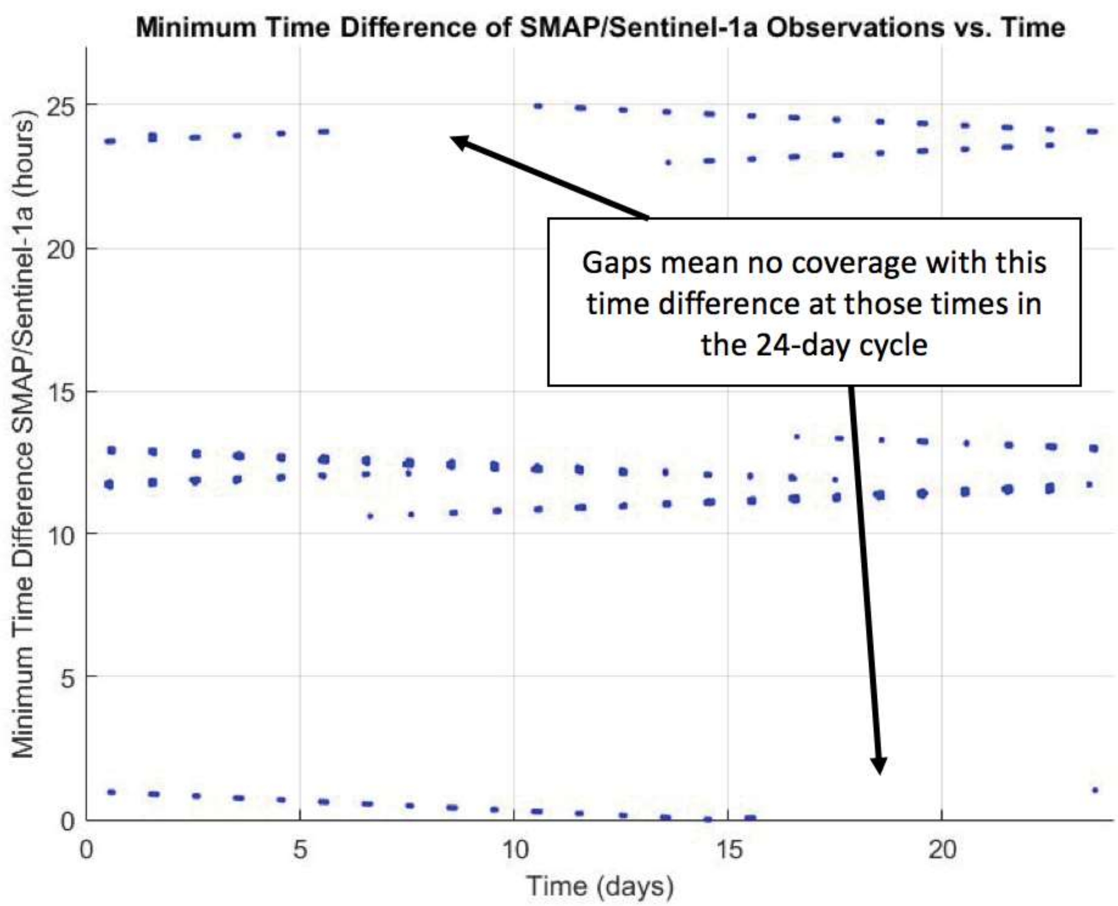

Figure 4 Minimum Time Difference of SMAP/Sentinel-1A Observations vs. Time.

Figure 5 shows the same as Figure 4 but with 1B data added. Due to 1B being 180 degrees offset from 1A, the observation time difference from SMAP is shifted in time from 1A by half of the common repeat cycle. This fills in the gaps shown in Figure 4.

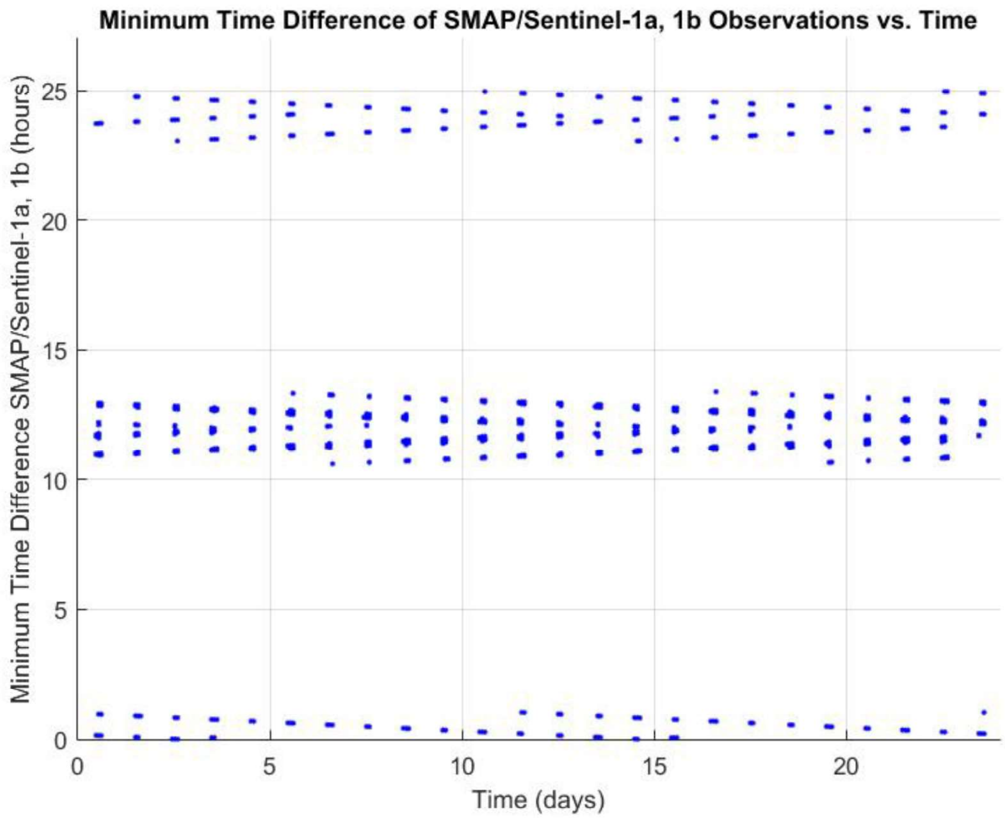

Figure 5 Minimum Time Difference of SMAP/Sentinel-1A & 1B Observations vs. Time.

COVERAGE STUDY RESULTS

The next step was to calculate the coverage for different combinations of observation time difference and number of Sentinel-1 assets. Figure 6 shows the results for the combinations studies. For comparison, the SMAP 1000 km swath (descending only) is shown in blue. The reason for showing descending only is because at the time of the analysis it was thought only descending passes (approx. 6 am local time flyover) was the only acceptable time for combining with Sentinel-1 data. That has since been expanded to include ascending passes, so the real cumulative coverage rates are actually somewhat better than that shown here (the 1.5 days referred to earlier). The reason for the step nature of each curve is due to the fact that the target area in question (contiguous US) is intermittently in view during the 24 day common repeat cycle. The reason for showing one asset (1A) versus two assets (1A and 1B) was to show the relative increase in cumulative coverage with the additional asset. From this plot it is clear that there is a great benefit to being able to use Sentinel-1 data that is within 1 day ("<26 hrs" in the plot) of a SMAP observation, when compared to just within a few hours. For both time differences, having two assets means achieving 100% coverage faster (7 days versus 12 days in the "<26 hrs" case).

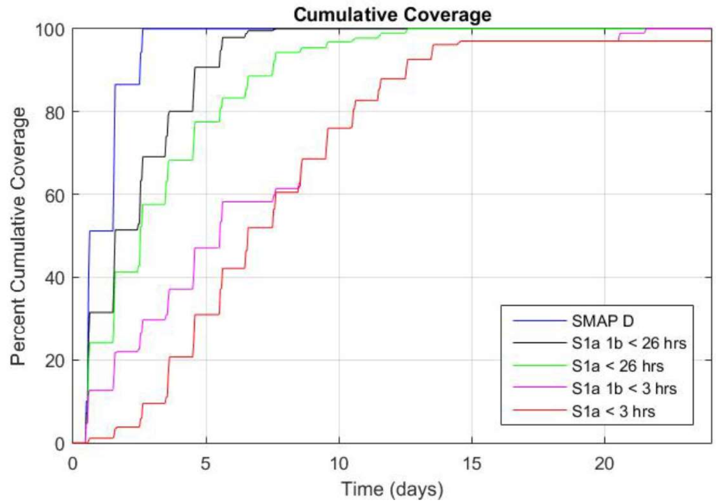

Figure 6 Rates of Cumulative Coverage over Contiguous United States for Different Time Windows and Sentinel-1 Combinations.

SCIENCE RECOVERY STATUS

From around Fall 2015, the Sentinel-1 project has steadily ramped up global coverage, including increased coverage over North America. Prior to the launch of Sentinel-1B, the maximum radar on-time allowable was 25 minutes per orbit. This was mostly due to a flight-ground data through-put limitation. Sentinel-1B commissioning phase demonstrated sustainable operations with a radar duty cycle of up to 40 minutes per orbit. This has enabled data collection in higher data rate radar modes (like the dual pol IW mode) for longer periods of time (see Figure 7).

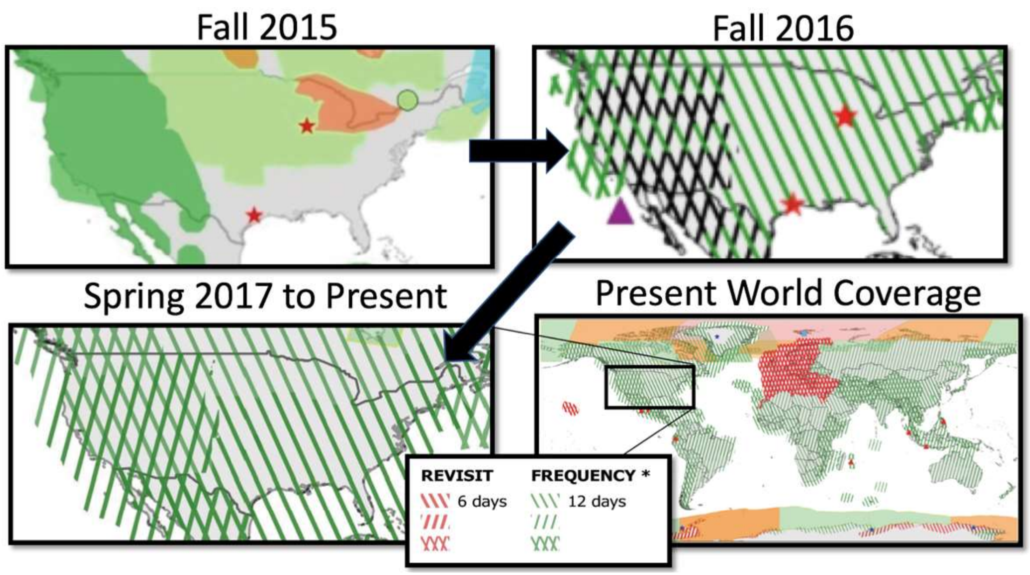

Figure 7 Sentinel-1 Observation Scenario History (N. America Zoom). Note the fall 2015 map format is due to only Sentinel-1A being in orbit, with a revisit frequency of 12 days.[*]

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[*] Cropped images from https://sentinel.esa.int/web/sentinel/missions/sentinel-1/observation-scenario

At the time of first engaging with the Sentinel-1 team (Fall 2015), only Sentinel-1A was in orbit, and the western half of the US was only covered in single pol IW mode (the darker green in Figure 7 Fall 2015), which was not useful to SMAP for recovering soil moisture. The eastern half of the US was covered in the dual pol IW mode, and only in one direction (primarily ascending). After the commissioning of Sentinel-1B was completed (Fall 2016), the dual pol IW mode coverage was increased to include more of the western US (green hatch marks), and with further use of the European Data Relay System (EDRS)[5], the coverage in this mode extended to all of North America. Additionally, global coverage went from about half to nearly all of the land area SMAP covers, with a revisit frequency that ranges from 6-12 days.

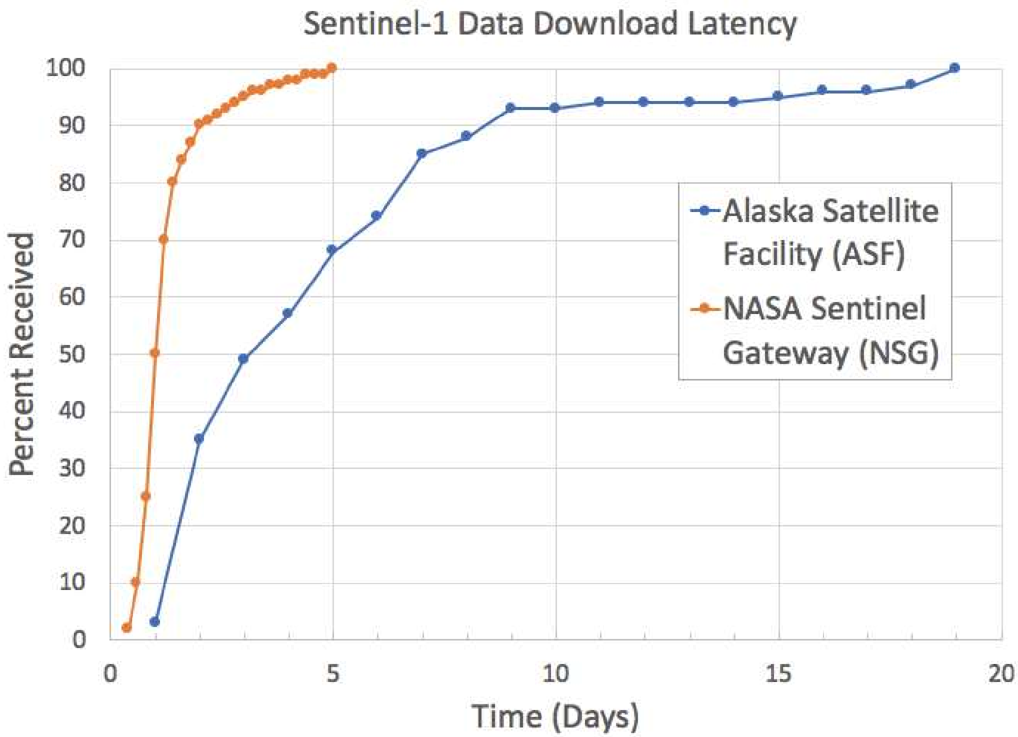

Figure 8 Sentinel-1 Data Download Latency.

When first developing the joint soil moisture product, the Sentinel-1 data was downloaded from the Alaska Satellite Facility (ASF). This is more of an archival data storage where low latency is not a driver. For an operational product that is used by weather agencies, a product that is 20 days out of date is less valuable than one that is mostly complete in under a few days. To reduce this latency for the operational data product, the SMAP Science Data System (SDS) team found that downloading from the same source that ASF does, the NASA Sentinel Gateway, provided the best possible latency, achieving 90% of the data in two days compared to almost nine days from ASF. Figure 8 shows this latency improvement. The beta version of the joint SMAP/Sentinel-1 product was released on November 2, 2017. The updated product was released on June 18, 2018.[*] The product spans all land within +/-60 degrees latitude.

[*] Data can be downloaded at https://nsidc.org/data/SPL2SMAP_S/versions/2

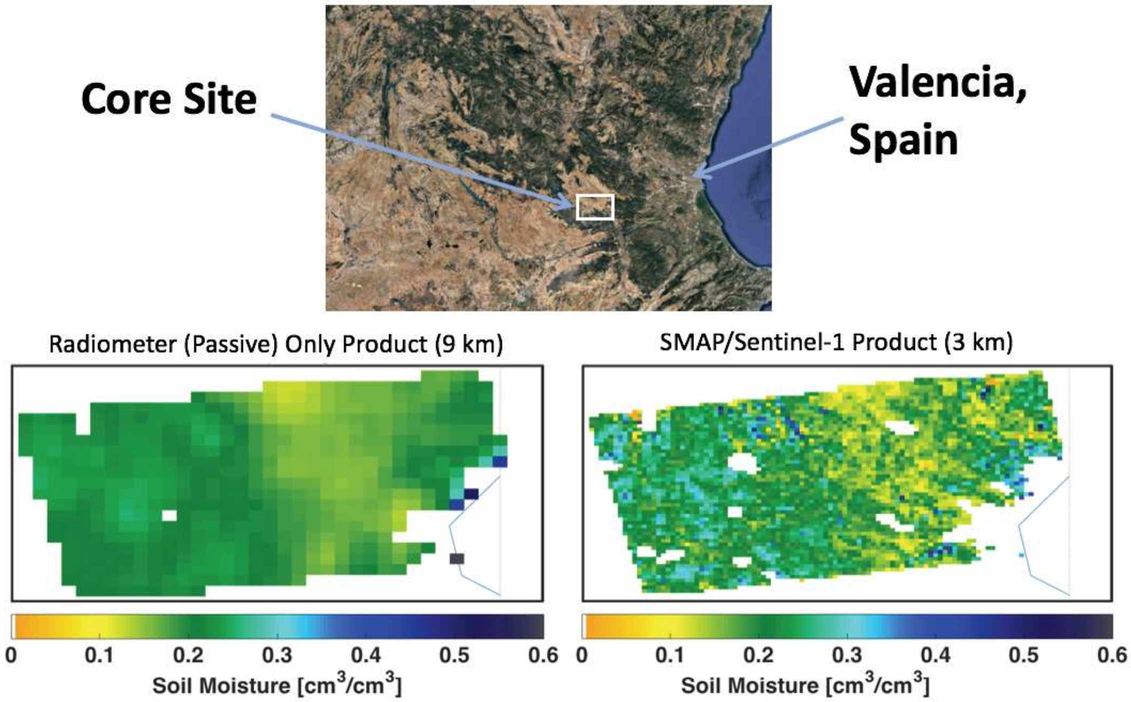

Figure 9 Sample High Resolution Soil Moisture Recovery Image[6]

CONCLUSION

The SMAP science requirements have been re-baselined and the increased coverage from Sentinel-1 has enabled a new data product combining both C-band and L-band measurements to produce soil moisture measurements with near global coverage every 6 days and a resolution of 3km (see Figure 9).[7] SMAP continues to produce data used by weather agencies and climate researchers around the world.

ACKNOWLEDGMENTS

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